Hand Prints and Handedness

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ASCERTAINMENT OF the roles of heredity in bringing about common nonpathological variations in human behavior entails difficulties not so likely to be encountered elsewhere. Concentrations of the occurrence of an uncommon variation within certain families is usually accepted as an indication that it may be inherited. But correlations between relatives with respect to a behavioral variation may also be used as evidence for the role of environment, for the child may have learned the behavior by association with and imitation of other members of the family. Gene frequency analysis may be employed to test simple modes of inheritance, but agreement between observed and expected frequencies of a trait does not necessarily prove its inheritance. It may be happenstance.

Perhaps the most convincing evidence of a genetic basis for a behavioral trait is to establish an association between it and a highly heritable physical variation which develops during fetal life, and which is not altered by postnatal circumstances. Such an association would indicate beyond reasonable doubt that the behavioral trait was influenced by heredity. There are at least two ways in which two hereditary traits may be associated. If they are due to two linked gene loci, one variant of trait A will go together with a certain variant of trait B in some families; but in other families the association will be in the opposite sense, and the population as a whole will show no association.

The second type of association results from the affects of one or more genes on both traits, or pleiotropy. Under these circumstances the correlation is always of the same type, and is evident in whole populations, as well as within families.

Handedness is a common behavioral variation, concerning which the importance of heredity is a topic of considerable controversy. There is no doubt that in many instances training can bring about a change. Europeans eat left-handed, whereas most Americans eat right-handed, yet they are of somewhat the same ethnic stock. Many left-handed children have been trained to write with their right hands. But the observation that handedness may sometimes be altered by no means rules out the possibility that heredity is also important.

There is a highly significant correlation between family relationship and similarities in handedness. In families where both parents are left-handed, about 50% of the children are left-handed; in families where only 1 parent is left-handed, about 17% of the children are left-handed; and in families where both parents are right-handed, only 6% of the children are left-handed (Rife, 1940). But as I have already pointed out, these correlations may be presented as evidence for either heredity or

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environment. They do indicate, however, that left-handedness is not due to a simple pair of recessive genes.

Intrapair differences, or "mirror-imaging," in handedness occur in approximately 20% of monozygotic twins. Newman, Freeman, and Holzinger, (1937) believed this phenomenon to be the result of relatively late separation of the embryos. This has not been substantiated by later findings (Rife, 1950), as there is little if any correlation between "mirror-imaging" in various traits in monozygotic twins, such as direction of hair whorls, dermatoglyphics, dentition, and handedness. Why, then, do some pairs show these differences, while others do not?

Investigations of the families of monozygotic twins, as well as those of dizygotic twins, have shown significantly higher frequencies of left-handedness among the immediate relatives of twins manifesting intrapair differences in handedness and pairs in which both members are left-handed, than among those of twins both of whose members are right-handed. It should be noted here that dizygotic twins show slightly more "mirror-imaging" in handedness than do monozygotic twins. A gene frequency analysis of over 500 pairs of twins revealed that the incidences of mirror-imaging in both types of twins agrees very closely to what would be expected if handedness is conditioned by a single pair of alleles lacking dominance, one homozygous condition resulting in right-handedness, the other in left-handedness, while the heterozygotes are ambidextrous. Those in the latter category are not predisposed either way, their handedness depending upon environmental factors. Mirror-imaging in monozygotic twins occurs in heterozygous pairs, possibly due to the operation of the asymmetry mechanism proposed by Newman. But whether monozygotic twins show the same or different types of handedness appears to depend upon the genotype of the twins rather than upon the period at which separation of the embryos occurred, (Rife, 1950).

Agreement with the gene frequency analysis does not necessarily prove that handedness is inherited in the manner proposed. It has also been noted (Verschuer, 1932) that observed frequencies in both types of twins agree closely with what one might expect on the basis of chance alone. If there were no data suggestive of heredity aside from family pedigrees and gene frequency analyses, one might be inclined to discount the importance of heredity. But there are associations between handedness and dermatoglyphics which present convincing evidence for a genetic basis for functional handedness.

The dermatoglyphic configurations on palms and fingertips are fully established after 18 weeks of fetal development, and are not altered thereafter. Moreover, they are highly heritable, and manifest tremendous variations from one individual to another. Any significant associations between dermatoglyphics and handedness thus appear to rule out any possibility that handedness is determined entirely by post-natal environment and training. Rife (1943) obtained evidence from family data that genes affecting handedness are linked with at least 1 pair which determine whorls on finger-tips and patterns in the fourth interdigital area of the palm.

Various investigators (Newman, 1934; Bettman, 1932; Cummins, Leche, and McClure, 1931; Cummins, 1940; Cromwell and Rife, 1942; Rife, 1943) have noted that associations characteristic of pleiotropy appear to exist between dermatoglyphics and handedness. In general, the hand prints of left-handers appear to possess more bilateral symmetry than do those of right-handers. That is to say, series of prints obtained from right-handers show greater total differences between right and left sides in the occurrence of patterns in the various areas than do those taken from left-handers. Although these observations are in general agreement, the differences are relatively small, of the order of from one to three percent. Obviously, very large numbers are needed to determine whether or not they are really significant. Unfortunately, most investigators have compared prints from only a few hundred individuals, whereas thousands are needed.

This report is concerned with the findings obtained from the prints of 3088 students at Ohio State University, who were students in an elementary genetics course. The investigation covered a period of approximately 10 years, and all students taking the course were required to provide data on handedness and dermatoglyphics. Patterns on the thenar/first interdigital area of the palm, and arches on the middle fingers were found to provide the best criteria of differences associated with handedness.

Several criteria were employed in the classification of handedness. These included preferred hand for throwing, writing, bowling, shooting marbles, tennis racket, driving a nail, sawing, whittling, and striking a match. Those definitely preferring the left hand for one or more of these operations were classed as left-handed. Undoubtedly many using the left-hand for only a few of these operations may be ambidextrous, but as we live in a right-handed world it is doubtful if any genotypic right-handers were included.

PATTERNS IN THE THENAR/FIRST INTERDIGITAL AREA

There are five areas on palms, on each of which patterns may or may not be present. Patterns consist of loops and whorls, and combinations of them. There are consistent and significant bimanual variations in the occurrence of patterns in each area. Patterns occur more frequently on right hands in the hypothenar, second, and third interdigital areas, whereas they occur more frequently on left hands in the thenar/first interdigital and fourth interdigital areas. These bimanual differences are greater in males than in females. Cromwell and Rife (1942) compared the prints of 600 right-handers with those of 753 left-handers, and found a trend towards reduction of bimanual differences, due chiefly to increases in patterns on the side having the lesser frequencies. This was found to hold true for all areas except the hypothenar, where the bimanual differences were the least of any of the areas. Although the trends were similar in each of the other four areas, they were only of the magnitude of approximately 1 to 2%. The same trend was noted for the occurrence of whorls on ring fingers, the finger characterized by highest frequencies of whorls. When the different areas were treated individually the differences were not statistically significant, but when pooled together the differences between right-handers and left-handers were significant.

The statistical significance of differences depends to some extent upon the ratios resulting from them. For example, an increase of from 1% to 3% is much more likely to be statistically significant than of from 49% to 51%. Equal increases in percentages are more likely to indicate significant differences at low rather than at intermediate frequencies, providing equal numbers of individuals are used in both comparisons. Patterns occur with intermediate frequencies on the third and fourth interdigital areas, whereas they occur with comparatively low frequencies in the thenar/first and second interdigital areas. Of the latter areas the thenar/first is more satisfactory for purposes of comparison, partly because of the rarity of second interdigital patterns among Caucasians. A review of the findings of various investigators shows that the most consistent differences in total pattern frequencies occur in the thenar/first interdigital area. Inspection of Table 1 shows increases in the frequencies of patterns in the thenar/first interdigital area among left-handers, the only exception being in the relatively small sample of Keith, where a small insignificant decrease was noted. Totals of all six investigations show an increase of approximately 3% among patterns in left-handers, the difference between right- and left-handers being highly significant.

The figures in Table 1 do not tell whether the increases among left-handers are due to proportional increases on both sides or to increases on one side only. Table 2

TABLE 1.—DATA CONCERNING THE TOTAL FREQUENCIES OF PATTERNS IN THE THENAR/FIRST INTERDIGITAL AREAS OF RIGHT-HANDERS AND LEFT-HANDERS

Investigator	Numbers of Individuals		Patterns			
			Right-handers		Left-handers	
	Right-handers	Left-handers	No.	Percent	No.	Percent
Cromwell	600	740	122	10.1	180	12.1
Keith	79	86	24	15.2	23	13.4
Newman	100	100	14	7.0	25	12.5
Bettman	200	100	66	16.5	58	29.0
Cummins and Leche	300	244	33	5.5	49	10.1
Rife (this investigation)	2716	372	556	10.4	98	13.1
Total.............................	3995	1642	815	10.20	433	13.17

$\chi^2 = 21.95$
$df = 1$
$p = < .000005$

TABLE 2.—THE DISTRIBUTION OF THENAR/FIRST INTERDIGITAL PATTERNS AMONG RIGHT-HANDERS AND LEFT-HANDERS

Handedness	Sex	Right Hand Only	Left Hand Only	Ratio Left to Right	Both	Total Number of Persons
Right........	♂	13–1.08%	128–10.68%	9.8:1	68–5.64%	1198
Right........	♀	19–1.25	106–6.98	5.5:1	77–5.07	1518
Right........	♂ + ♀	32–1.17	234–8.61	7.3:1	145–5.30	2716
Left..........	♂	7–3.57	29–14.79	4.1:1	13–6.63	196
Left..........	♀	6–3.40	8–4.54	1.3:1	11–6.24	176
Left..........	♂ + ♀	13–3.48	37–9.94	2.8:1	24–6.45	372

shows the distribution of thenar/first interdigital patterns among 3088 students according to handedness, sex, and side. Note the consistent decrease in ratio of left to right among left-handers as contrasted with right-handers. This holds true for both males and females, although bimanual differences are greater among males than among females. The most striking difference is the increase of patterns on right-hands among left-handers, an increase of from slightly over 1% to almost 3.5%. Patterns on left hands show increases among left-handed males and decreases among left-handed females. No real differences are indicated in the frequencies of individuals having patterns on both hands.

The higher pattern frequencies among left-handers are due chiefly to higher frequencies of individuals having patterns on right hands only. This results in a lower bilateral asymmetry in the population of left-handers, as contrasted with the right-handers. This is in accord with the trends indicated in earlier investigations, and found in other pattern areas. The differences between right- and left-handers are highly significant, as shown in Table 6-b.

ARCHES ON MIDDLE FINGERS

Cromwell and Rife (1942) found a slightly higher frequency (1.3%) of whorls on left ring fingers of left-handers than of right-handers among those lacking whorls on the right ring finger. Although this is a trend towards lower bimanual asymmetry, the difference was statistically insignificant. Moreover, whorls occur on around 70% of the ring fingers among Caucasians, thus necessitating the collection of a tremendous number of prints to determine whether or not these differences appear to be significant. I decided, therefore, to compare the distribution of arches on middle fingers among right-handers and left-handers. Arches are actually patternless configurations having ridge counts of zero, whereas whorls with large counts are at the opposite phenotypic extreme.

Ridge counts have been estimated to possess a heritability of 90% (Holt, 1952). Genes affecting finger-tip patterns appear to affect all digits, although the incidences vary bimanually and from one finger to another. Arches occur with greatest frequencies on the left middle finger. The total frequencies of arches among North American Caucasians are from about 4% to 7%, thus rendering it feasible to test the significance of small differences with fewer numbers of individuals than would be required to run similar tests for whorls.

TABLE 3.—THE DISTRIBUTION OF ARCHES ON MIDDLE FINGERS AMONG RIGHT HANDERS AND LEFT-HANDERS

Handedness	Sex	Right Fingers Only	Left Fingers Only	Ratio Left to Right	Both	Total Number of Persons
Right..........	♂	25–2.04%	48–4.00%	1.9:1	35–2.92%	1198
Right..........	♀	27–1.78	95–6.25	3.5:1	56–3.68	1518
Right..........	♂ + ♀	52–1.91	143–5.26	2.7:1	91–3.35	2716
Left............	♂	6–3.06	9–4.59	1.5:1	5–2.55	196
Left............	♀	7–3.98	7–3.98	1:1	4–2.27	176
Left............	♂ + ♀	13–3.49	16–4.30	1.2:1	9–2.41	372

The distributions of arches on middle fingers are shown in Table 3. The trends throughout parallel those recorded for the distributions of thenar/first interdigital patterns in Table 2. Both males and females show reductions in the ratios of arches on lefts only to rights only, due mostly to increases of arches on right fingers. Table 6-c shows that the increase is statistically significant, although not highly so. The lesser significance of the increase in arches is probably due to the fact that the ratio of left only to right only is smaller among the right-handers than the corresponding ratio for thenar/first interdigital patterns among right-handers. Table 6-a shows the combined distributions of thenar/first interdigital patterns and arches on middle fingers. The differences between right-handers and left-handers are highly significant. The calculated frequencies are enclosed in parentheses beneath the observed. Note that the greatest deviations between observed and calculated are for the occurrence of thenar/first interdigital palm patterns, and arches on the middle fingers of right hands only.

A further comparison was made between the finger prints of 12 families consisting entirely of right-handers, and those of 25 families of whom one or more members of each were left-handed. Almost 30% of these from families having left-handers were classed as left-handed. If one assumes that most persons heterozygous for handedness become functional right-handers because of their environments, he may assume that the gene for left-handedness occurs with a frequency of over 50% within these families. Where both parents are right-handed, each would have to be heterozygous to produce left-handed children, and where one or both are left-handed the frequencies of the gene for left-handedness would tend to be above 50%. Families consisting entirely of right-handers should have much higher frequencies of the gene for right-handedness. If the family groups are sufficiently large, we should expect to see these

TABLE 4.—THE DISTRIBUTION OF ARCHES ON MIDDLE FINGERS AMONG 25 FAMILIES OF WHICH ONE OR MORE MEMBERS OF EACH ARE LEFT-HANDED

Handedness	Sex	Arches			Total Number of Persons
		Right only	Left only	Both	
Right.........	♂	4	0	7	78
Right.........	♀	1	3	4	86
Left..........	♂	1	3	3	36
Left..........	♀	1	2	0	33
Totals..................		7–3.0%	8–3.4%	14–6.0%	233

TABLE 5.—THE DISTRIBUTION OF ARCHES ON MIDDLE FINGERS AMONG 12 FAMILIES, ALL OF WHOSE MEMBERS ARE RIGHT-HANDED

Sex	Right Only	Left Only	Both	Total Numbers Persons
♂	1	2	2	31
♀	0	3	2	32
♂ + ♀	1–1.58%	5–7.9%	4–6.63%	63

TABLE 6.—TESTS FOR SIGNIFICANCE OF DIFFERENCES

a. Distributions of arches and thenar/first interdigital patterns

	None	Right Only	Left Only	Both	Total	χ^2	*df*	*p*
Right-handers	2049 (2029.8)	84 (96.8)	337 (343)	246 (246.4)	2716	15.97	3	.001 (approximately)
Left-handers	260 (279.2)	26 (13.2)	53 (47)	33 (32.6)	372			

b. Frequencies of thenar/first interdigital patterns on right only

	Right Only	Not on Right Only	Total	χ^2	*df*	*p*
Right-handers	32	2684	2716	12.72	1	<.0005
Left-handers	13	359	372			

c. Frequencies of arches on middle fingers, right only

	Right Only	Not on Right Only	Total	χ^2	*df*	*p*
Right-handers	52	2664	2716	4.00	1	Between <.05 and .01
Left-handers	13	359	372			

d. Comparisons of the ratios of arches on middle fingers, left-handers + families with 1 or more left-handers versus right-handers + families, all of whose members are right handed

	Right Only	Left Only	Total	χ^2	*df*	*p*
Left-handers + families with left-handers	20	24	44	6.29	1	<.01 (approximately)
Right-handers + families with no left-handers	53	148	201			
Total	73	172	245			

differences reflected in the hand prints. Tables 4 and 5 show the distributions of arches within the two family groups. (Palm prints were not available for comparisons.) Note that differences are indicated, the right-handed group showing opposite asymmetry to the left-handed group. In view of the fact that the family groups are not large enough to show significant differences between them, the frequencies of arches, on one side only, within the family group were pooled with those of the student populations, as shown in Table 6-d. Note that the left-handers and the families with left-handers differ with a high degree of significance from the right-handers and families of right-handers.

THE CROMWELL SERIES

Subsequent to the analysis of the student data, a similar analysis of the distribution of arches on the middle fingers was made of the prints in the Cromwell series

TABLE 7.—THE DISTRIBUTION OF ARCHES ON MIDDLE FINGERS AMONG RIGHT-HANDERS AND LEFT-HANDERS IN THE CROMWELL SERIES

Handedness	Sex	Right Fingers Only	Left Fingers Only	Ratio	Both	Total Number of Persons
Right	♂	6–2.1%	18–6.3%	3:1	4–1.2%	284
Right	♀	7–2.4	25–8.6	3.5:1	14–4.3	288
Right	♂ + ♀	13–2.2	43–7.5	3.3:1	18–3.1	572
Left	♂	15–3.6	16–3.9	1:1	11–2.6	409
Left	♀	14–4.3	15–4.6	1:1	11–3.4	323
Left	♂ + ♀	29–3.9	31–4.2	1:1	22–3.0	732

TABLE 8.—FREQUENCIES OF ARCHES ON MIDDLE FINGER, (RIGHT ONLY) COMBINED STUDENT AND CROMWELL DATA

	Right Only	Not on Right Only	Total	χ^2	df	p
Right-handers	65	3223	3288	11.56	1	$<.001$
Left-handers	42	1062	1104			

(Cromwell and Rife, 1942). These prints were collected from Caucasian school children in southwestern Ohio, and include those of 732 left-handers and 572 right-handers. The findings are recorded in Table 7. Note that the distributions correspond closely with those in the student population (Table 3). The incidence of arches on right hands only shows highly significant differences between left-handers and right-handers in the combined student and Cromwell series (Table 8).

DISCUSSION

The consistency and significance of the differences between right-handers and left-handers with respect to thenar/first interdigital palmar patterns and arches on middle fingers confirm earlier indications that prints of groups of left-handers manifest less bimanual asymmetry than do prints from groups of right-handers. That is to say, the bimanual variations are reduced in the total pattern frequencies of a large group of left-handers, although the number of individuals manifesting asymmetry is increased. For example, suppose prints are obtained from 100 right-handers and 100 left-handers. Six of the right-handers and also six of the left-handers have thenar/first interdigital patterns on both hands; among the right-handers 10 have these patterns on the left hand only and one has it on the right hand only; among the left handers 10 have the patterns on the left only while 4 have them on the right hand only. Among the 100 right-handers we have a total of 16 patterns on left hands and 11 on right hands, whereas among the 100 left-handers, 16 have patterns on left hands and 14 have them on right hands. The left-right pattern ratio among right-handers is 16:11, whereas it is 16:14 among the left-handers. Thus the total bimanual asymmetry is less for the 100 left-handers than for the 100 right-handers. But there are only 7 individuals among the right-handers who show bimanual asymmetry, whereas 10 of the left-handers show it. In other words, *individual* bilateral asymmetry is greater while *group* asymmetry is lesser among left-handers than among right-handers.

It should be kept in mind that these differences are of a minor nature, and are apparent only when large numbers of prints are compared. Even though the relative frequencies of thenar/first interdigital patterns and arches on middle fingers are greater among left-handers than among right-handers, the majority of people who possess either of these configurations are right-handers. According to our findings, 1 out of every 5 persons having a thenar/first interdigital pattern on the right hand only is a left-hander, and approximately 3 out of every 10 persons having an arch on his right middle finger and not on his left one, is also a left-hander. But left-handers are over 3 times as likely as right-handers to have thenar/first interdigital patterns on right hands only, and over twice as likely to have arches on the right middle finger. What may at first appear to be a discrepancy between the last two statements is due to the fact that only a small proportion of the population is left-handed.

The reason for these differences between right- and left-handers is still a matter of conjecture. Presumably the expressivities of many of the genes affecting dermatoglyphic configurations are variable, dependent upon the individuals genotype with respect to handedness. It is of interest to note that the palmar dermatoglyphics of mongoloid imbeciles deviate markedly from those of normal persons, one of their most striking features being the accentuation of normal dextral trends. Patterns occur with unusually high frequencies on the second and third interdigital areas, and with unusually low frequencies on the fourth and thenar/first interdigital areas. In at least the latter respect, the deviation from normal right-handers is in the opposite direction to that observed among left-handers.

Why do patterns occur on both hands of some persons, and on only one hand of others? Possibly those showing them on one side only are heterozygous or genotypically intermediate; that is to say they are genotypically near a threshold for the pattern expression. The embryos of left-handers may develop more symmetrically than do those of right-handers. Among the former it is more a matter of chance as to which hand a single pattern develops upon, than it is among the latter. The final solutions to these intriguing problems in human developmental genetics must await further investigation.

SUMMARY

Extensive comparisons of the finger and palm prints of right-handers with those of left-handers reveal slight but consistent and highly significant trends towards greater bilateral symmetry among groups of left-handers.

These trends are most readily apparent through comparisons of the distributions of patterns on the thenar/first interdigital area of the palm and arches on middle fingers. These associations between dermatoglyphics and handedness, as well as those indicating linkage, demonstrate conclusively that handedness cannot depend solely upon postnatal circumstances. The phenotypic expression of handedness is dependent upon both heredity and environment.

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